INTERNATIONAL MULTIDISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT
SJIF 2019: 5.222 2020: 5.552 2021: 5.637 2022:5.479 2023:6.563 2024: 7,805
eISSN :2394-6334 https://www.ijmrd.in/index.php/imjrd Volume 11, issue 03 (2024)

EVOLUTION AND COMPARISON OF MINIMALLY INVASIVE METHODS IN THE DIAGNOSIS AND TREATMENT OF CHEST DISEASES

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Annotation: The evolution of VTS begins with the concept of the early endoscope and does not appear to end. It is clear that these MIS approaches offer the advantages of traditional thoracotomy; however, there is conflicting evidence about how they relate to each other. This review suggests that further randomized trials and meta-analyses are needed to confirm which minimally invasive approach is most beneficial for chest conditions.
Keywords: Video-assisted thoracoscopic surgery (VATS); video-assisted thoracoscopy (VTS), muscle-sparing thoracotomy (MST), robot-assisted thoracoscopy (RATS), minimally invasive surgery (MIS); story; evolution; comparative results.

History of video thoracoscopic operations (VTS).

The first evidence of a device capable of visualizing the internal structures of the human body was published by Dr. Bozzini, a German urologist, in 1806 (39,78).

This device, known as the Lichtleiter, used beeswax, candles, and a silver speculum to examine the female genitalia, vagina, bladder, rectum, and upper respiratory tract (83,78).

In 1853, based on the work of Bozzini, Antonio Desormeaux developed a lens that could focus light on the internal structures of the body, making images clearer and brighter (44,78.).

In 1879, this lens was improved by Maximilian Nitze, he introduced the cystoscope - a device consisting of a working channel, a light source and an optical lens, which provided better visualization of body cavities (44,78.).

George Kelling, taking all these concepts into account, developed instruments for laparoscopic operations on the pelvic and abdominal organs. In 1929, the first successful laparoscopic surgery on a human was performed (44.78).

With the development of endoscopic instruments, the road was opened for Hans Christian Jacobeus, professor of internal medicine in Sweden. He used Kelling instruments to visualize the chest (44,78). In 1910, Jacobeus succeeded in using endoscopic instruments to visualize the lung and pleural cavity, pioneering what is now known as modern thoracoscopy (44,78).

Jacobeus noted that these procedures are quite effective in eliminating pleural adhesions and preventing pneumothorax resulting from tuberculosis (44,67,78). He also proposed diagnostic criteria for lung cancer, working closely with thoracic surgeon Einar Kay to provide thoracoscopic descriptions of lung tumors before resection (67,78).

Although thoracoscopy was used in the early 1920s in Europe, it was not until the 1970s that it was widely used in North America (44,78).

With the advent of new endoscopic instruments, such as the surgical stapler, for suturing organs, it has now become possible to use it in pulmonary resection (33,78.).

In 1991, Giancarlo Roviaro performed the first video-assisted thoracoscopic (VTS) lobectomy in Milan, on a 71-year-old man to remove a tumor of the lower lobe of the right lung (77,78). From this day on, a new era of thoracoscopic operations began, which is increasingly used for the diagnosis and treatment of various diseases of the lungs, pleura and mediastinum.

Until the early 2000s, traditionally open thoracotomy and surgical pleurectomy were accepted as standard treatments for spontaneous pneumothorax as well as pleural mesothelioma (1,2,62,65).

The traditional procedure with a wide skin incision and expansion of the intercostal space is associated with extensive injuries to the pectoral muscles and intercostal nerve. Persistent pain during thoracotomy increases the required dosage of analgesics and restrictions on physical movement, which ultimately leads to a delay in postoperative recovery (62,81.). Many surgeons want to overcome the disadvantages of open thoracotomy by reducing its invasiveness. VTS has become popular since the 1990s, and the increase in the number of thoracic operations has required thoracic surgeons to look for new ways of minimally invasive manipulation for various pulmonary diseases. With the development of thoracoscopy and other instruments, open thoracotomy was gradually replaced by VTS.

Results and prognosis of VTS compared with thoracotomy.

Compared with thoracotomy, VTS technology has demonstrated clear postoperative benefits. A meta-analysis and systematic review by Cheng et al [2007] summarized the findings of 205 patients in 36 randomized trials and 3589 patients in 33 non-randomized trials (41.77). The authors demonstrate many advantages of VTS compared with open thoracotomy, including: reduced blood loss; reduction of pain in one day, one week and 2-4 weeks; reduced need for analgesics after surgery; improving quality of life. Reduction of hospital stay by 2-6 days and reduction of time between surgery and chemotherapy (41.78.).

Bendixen M et al [2016] compared VTS lobectomy (n=102) with conventional thoracotomy (n=99) for stage I non-small cell lung cancer (NSCLC) to assess differences in postoperative pain and quality of life (34,78.). The researchers found that pain was significantly lower in the VTS group at 24 hours, and this group also experienced a lower incidence of moderate-to-severe pain over 52 weeks, reducing hospital stays (34,78). Quality of life scores were significantly higher in the VTS group using the EuroQol 5 Dimensions questionnaire; however, it should be noted that there were no significant differences between the European Organization for Research and Treatment of Cancer and the quality of life questionnaire (34,78).

The VIOLET study is the most recent randomized controlled trial comparing VTS with open lobectomies for early stage lung cancer (64,78). In this experiment, 503 participants were randomly selected and underwent either VTS (n=247) or open lobectomy (n=256) (64,78). The EORTC QLQ-C30 study showed that patients who underwent VTS experienced superior postoperative results, with recovery of physical function as early as 5 weeks, than compared with open lobectomy (64,78). The VTS group also had a shorter length of hospital stay, fewer severe adverse complications after surgery, and a shorter duration of pain at the incision site (64,78). It is worth noting that the method of performing thoracotomy was not controlled and was chosen by the surgeon according to preference.

A meta-analysis by Cheng D et al [2007] found no difference by stage in 5-year survival when comparing VTS with open lobectomy (41.78). Another related multi-institutional study by Shigemura et al. [2006] compared the results of treatment of 145 patients with clinical stage non-small cell lung cancer in three treatment groups: complete VTS (s-VTS), assisted VTS (a-VTS) and open lobectomy (84 ,78.).

After an average of 38.8 months of postoperative follow-up, there were no significant differences in 5-year survival: Kaplan-Meier survival probability was 96.7% for c-VTS, 95.2% for a-VTS, and 97.2% for open lobectomy (78,84.). A more recent study by Higuchi et al. [2014] examined long-term outcomes of VTS lobectomy and found no statistically significant difference in 5-year survival compared with open lobectomy (54,78).

Mouroux J et al (68,78) proved that VTS is indeed an alternative to open thoracotomy for the treatment of many diseases of the lungs and pleura, showing acceptable results. Lim E et al (64,78) conducted a cross-sectional, multicentre randomized trial to compare outcomes in early

stage lung cancer between VTS and open resection. They demonstrated significantly better physical and functional results in the VTS group (64,78).
Expanding the scope of military-technical cooperation.
The VTS method also allowed for use with non-intubated anesthesia (NMA) (51,77.). Nezu et al [1997] were among the first to introduce NMA using VTS for bulla resection in the treatment of spontaneous pneumothorax (71,78). In particular, these surgeons used lidocaine 0.5% for local anesthesia and intravenous potentiation of diazepam or butofol in order to eliminate the need for general anesthesia (71,78.). A meta-analysis and systematic review by Yu MG et al. [2019] confirmed that IMA in VTS, metastasectomy, and segmentectomy are associated with shorter hospital stay, lower estimated hospitalization cost, decreased length of chest tube stay, and shorter postoperative recovery time compared to intubation general anesthesia (71,78.).
The development and use of VTS has also made it possible to perform surgical intervention in situations where thoracotomy has traditionally been considered too high-risk. Donahoe et al [2017] conducted a retrospective analysis to see if patients at increased risk with low pulmonary function could undergo VTS lobectomy without increasing postoperative complications (45,78).
This analysis included 608 patients undergoing lobectomy between 2002 and 2010 and classified them as either at high risk (one second expiratory volume (FEV1<50%)). Increased-risk thoracotomy patients experienced more pulmonary complications compared with standard-risk patients (45,78). It is interesting to note that when VTS was used (45,78), there were no significant differences in pulmonary complications between the high- and standard-risk groups.

Muscle-sparing thoracotomy and results compared with VTS
The first mention of the TBM technique appeared in the literature in 1973, where Noirclerc et al described a technique to avoid excision of the latissimus dorsi muscle (74,72).
Since then, many methods have been developed, but the first to use the TBI method is considered to be the American surgeon Karwande S.V. in 1989 (46).
This method involves an incision from the anterior axillary line, extending to the tip of the scapula and moving superiorly and posteriorly between the scapula and the spine (60.). The skin flaps are spread using an electric cautery along the back side of the latissimus dorsi muscle, the serratus anterior muscles are moved apart from the chest wall without an incision (60.)
Initial randomized trials, including Hazelrigg SR et al. [1991], confirmed that those undergoing TBI have reduced pain perception compared with those undergoing standard thoracotomy (53,78). Another randomized trial concluded that drug use in the first 24 hours was lower in the BMT group compared with standard thoracotomy (29). Following the introduction of the VTS technique for lung resection, a meta-analysis was conducted to determine whether the BMT technique had any advantages over VTS (90). Wang Z et al. [2019] evaluated 10 studies with 1514 patients and concluded that hospital stay, chest drain time, and intraoperative blood loss were reduced in the VTS group compared with the TBI group, suggesting that that military-technical cooperation may still be preferable (90.).
Uniportal VTS and results compared to multiport VTS.
Single-port VTS is a procedure in which all endoscopic procedure instruments, including the camera, clamp and endo-stapler, are inserted through a small single hole measuring between 2.0 to 3.5 cm (50,57,86). There are a number of surgical considerations that should be taken into account when calculating VTS from a single port. Compared to three-port VTS, in which instruments can be applied to the surgical site with a diamond-shaped geometric configuration to obtain a sufficient surgical field, single-port VTS requires an angled thoracoscope
and many more articulatory mobile tools to solve the problem (76). For these reasons, some thoracic surgeons consider single-port VTS to be an ergonomic, inconvenient method due to

instrument collision and limited field of view, and they think that the operation will take a long time. Careful dissection to avoid injury to blood vessels in the muscle layer and intercostal space is a prerequisite to prevent bleeding. However, bleeding can damage the camera lens and lead to poor visibility and difficulty in surgery. Many thoracic surgeons adopt a wound protector to protect the intercostal nerve as well as to provide a clean operative window for single-port VTS (55,50,86,85).

A conventional VTS is made from three ports - a chamber, a clamp, and an endo-stapler. The minimally invasive surgical procedure is evolving towards reducing the number of ports to reduce their invasiveness. Yamamoto H et al (47.) reported successful resection of a segment for pneumothorax through a single port. In 1998, Rocco G et al (76.) reported the first case of single-port VTS with a 2.0 cm skin incision for the treatment of spontaneous pneumothorax using a 5 mm thoracoport and articulation instruments. Since then, single-port VTS began to attract the attention of many surgeons. Already in 2004, Rocco G et al reported successfully performing 15 wedge resections using single-port VTS in the treatment of interstitial lung diseases (76.).

Although the potential benefits of single-port versus multi-port VTS may seem plausible, there is inconclusive evidence for improved outcomes from both randomized trials and meta-analyses. One randomized trial by Sano Y et al [2021] compared pain scores in patients undergoing pulmonary resection using single-port or multiport VTS and found that pain scores on postoperative days 2, 3, 5, and 10 were reduced in single-port VTS. group (80.).

Similarly, Yao J et al. [2020] found no differences between the single-port and multiport groups with respect to length of chest tube placement, length of hospital stay, or pulmonary function (49.). Interestingly, the researchers concluded that the mental and physical demands were less for surgeons to use a single-port procedure (49.).

Both randomized trials and comparative meta-analyses show conflicting data from single-port procedures compared with multiport VTS. A meta-analysis by Harris C G et al [2016] concluded that compared with VTS, single-port techniques reduced postoperative pain and paresthesia, and improved quality of life for patients (52.). Xiang Z et al. [2023] also compared single-port and multiport VTS for NSCLC segmentectomy and found that the single-port VTS group had a shorter length of hospital stay, decreased chest tube exposure, and complete pain relief on the third day (92.). Similarly, Abouarab A A et al. [2018] reported that single-port VTS resulted in a reduction in postoperative pain, blood loss, hospital stay, and chest drain time (28).

However, the vast majority of surgeons are hesitant to adapt to single-port VTS. The biggest reason for not using the method is the discomfort of the instruments colliding and the difficulty of ensuring sufficient visibility, and insufficient maneuvering in the pleural cavity.

Paresthesia, chronic pain after thoracotomy is defined as pain
which persists for 2 months after thoracotomy. It was described in 1945 by Blades, chronic intercostal pain in a patient following thoracotomy during the Second World War (36.). The etiology of CMB has been attributed to nerve damage, neuropathic pain, and dysesthesia such as numbness, hyperalgesia, and somatic pain over a long period of time. In summary, patient-reported paresthesia may be a component after thoracic surgery (82). The characteristic of paresthesia is mild pain that does not disappear or disappears after taking conventional painkillers (82.).

The incidence of paresthesia is estimated to be 11–80% (34). Paresthesia may persist for several years after surgery. Sihoe et al (82) found that 21% of patients undergoing VTS had paresthesia 12 months after VTS.

pleurodesis. The main goal of VTS is to improve acute and chronic postoperative pain.

In general, many surgeons believe that single-port VTS causes less nerve damage than three-port VTS, and therefore paresthesia will be less with a single-port VTS. (57,79,48,58, 56,70,91.).
Yang H C et al (48.) reported a lower rate of paresthesia in the single-port group compared with the three-port group (33.3% vs. 76.9%, respectively; P = 0.01) (48.).
Suboxyfoidal incisions and their relative results
Although VTS techniques are less invasive than thoracotomy, placement and removal of specimens through the intercostal spaces results in widening of the ribs and possible intercostal nerve damage (30). In addition, in cases where the lung tissue interfered with manipulations inside the pleural cavity or mediastinum, with pathologies of the anterior mediastinum, damage to the lung tissue is possible (30.). To avoid these possible difficulties of intercostal space incisions, suboxyfoidal approaches have received attention (30.). Theoretical advantages of this approach include: reduction of chronic and acute pain, as well as the ability to remove larger volumes of tissue without restrictions than the intercostal space (30.).
With this technique, a 3-5 mm incision is made below the xiphoid process, followed by dissection of the linea alba and blunt dissection above the level of the diaphragm (30.). Studies have shown that suboxyfoidal approaches to the lungs and mediastinum can lead to reduced pain at 1 and 3 months, as well as improved quality of life, compared with VTS (42.). It is worth noting that the suboxyfoidal approach is not without any risks or potential complications. A study by Chen Z et al [2022] recently found an increased risk of cardiac arrhythmia with suboxyfoidal procedures compared with single-port VTS (43.).
However, there was less pain in the suboxyphoid incision group, measured on a numerical scale at 24 and 48 hours (43). More prospective, preferably randomized controlled trials, are needed to further evaluate suboxyfoidal methods compared with VTS.
History of robotic surgery and results compared with VTS.
The word robot comes from the Czech word "robota", which translates directly in English to the word "hard labor", "hard work", (88.).
The history of robotic devices dates back to 1495, when Da Vinci built the "Metal Warrior" with structures resembling a human jaw, arms and neck (88.). However, this concept did not appear until 1921 in Karel Capek's play Rossum's Universal Robots (88). After the film adaptation of this play, the word “robot” entered the world’s concepts as a name for a machine that is similar to a person and does work for him. The first published use of robotics in surgery was described half a century later in 1988 when Kwoh et al performed a highly accurate brain biopsy using a Unimation Puma 200 robot (63). Shortly thereafter, the same robotic system was used to perform transurethral resection of the prostate (88). In 2001, Dr. Marescaux of New York was the first to perform a successful, completely distant laparoscopic cholecystectomy on a patient in Strasbourg, France (66.).
In the early 2000s, thoracic surgeons began using robotics to perform lung resections, a technique known as RVTS (75.). The robotic apparatus used was the Da Vinci system, which consists of a connected surgical manipulator to two instrument arms, as well as a central arm equipped with an endoscope (69.). It should be noted that this system is a remote manipulation system, meaning that the instruments are controlled by a surgeon at a remote location (69.).
The first information about the use of RVTS for anatomical resection of the lungs was described by Melfi F M et al. [2002], Mariani A M et al. [2003], as well as Bodner J et al. [2004] (37.69.). These surgeons used the da Vinci system to perform a variety of thoracic procedures, including lobectomy, tumor enucleation, bulla suturing procedures, esophageal opening, and fundoplication (37,69). They noted relatively similar postoperative courses among patients, and emphasized the potential benefits of robotics in the future of thoracic surgery (37,69).

SJIF 2019: 5.222 2020: 5.552 2021: 5.637 2022:5.479 2023:6.563 2024: 7,805
eISSN :2394-6334 https://www.ijmrd.in/index.php/imjrd Volume 11, issue 03 (2024)

Cerfolio R J continued to improve on previous robotic techniques used in RVTS and developed his own approach to robotic lobectomy using 4 robotic arms in the early 2000s (40.).
Ramadan O I et al [2017] also recently outlined an approach that used 4 ports: an 8mm right robotic port, a 12mm camera port, a 5mm robotic arm and a 12mm assistant port to perform the operation (75.). Compared to conventional two-dimensional images provided by VTS, the robot-assisted approach provides a three-dimensional, high-definition enlarged image of the chest (75.). The use of robotic arms can also improve the precision and maneuverability of surgical instruments (75.). However, it should be noted that the approach based on the use of RVTS does not allow direct palpation of structures in the lungs, which is possible using VTS methods (75.). In addition, robotic procedures take longer and may be more expensive, but despite all this they can be effective (35.).
Given the technical advantages of RVTS, the question must be asked: are the results similar when compared to the VTS method? A national database review by Kent M et al [2014] analyzed outcomes for RVTS, thoracotomy and VTS in 33,095 patients (61). Compared with thoracotomy, robotic surgery reduces mortality, length of hospital stay, and overall complication rates; however, when compared with VTS, robotic surgery did not show any statistically significant differences (61.). Conversely, a meta-analysis by Zhang J et al. [2022] found that compared with VTS techniques, the procedures resulted in less blood loss, shorter hospital stay, and greater 5-year pain-free survival than RVTS (93.).
Thus, it is clear that more prospective randomized studies are needed to clarify whether differences truly exist between the two methods. It is worth noting that a recent report by Rocha Junior and Terra [2022] suggests that RVTS offers a shorter training course and improved quality of lymphadenectomy (52.).
Training in minimally invasive surgery
Although research has been conducted to standardize training courses for different MIS approaches, many experts report varying numbers of activities required to acquire skills. It has been suggested that 50 VTS procedures are required to perform this technically challenging operation; however, other experts argue that experienced surgeons can gain the necessary experience in as few as 20 cases (52,73.). Further examination of the literature indicates that surgeons require between 18 and 32 robotic procedures to achieve proficiency in RVTS (87.). Andersson S E et al [2021] suggest that the training course for VTS and RVTS is similar and perhaps less challenging for RVTS if the surgeon has previous experience in the field of VTS (31.). Bedetti B et al [2017] suggest that a training phase of 30 uniportal VTS lobectomies is sufficient to lead to a reduction in conversion rates and complications such as prolonged air leaks in subsequent operations (32.).
Although researchers have succeeded in quantifying the learning curve for various MIR techniques, there are several external factors that determine how long it will take to actually master each procedure. For example, training programs with a higher workload allow trainees to repeatedly apply this new method in a shorter time (73.). Courses of study can also be shortened when trainees have a thorough understanding of lung anatomy and its many anatomical variations (73.). In the case of VTS lobectomy, experience with other procedures such as VTS wedge resection and segmentectomy can provide the basis for effective port placement, bypassing training courses (73.). To gain skills in robotic surgery, robotic surgical simulators can be used to enhance the training of surgeons (73.).
For example, the daVinci Skills simulator provides specific simulation with step-by-step guidance for performing robotic lobectomy while providing postoperative feedback (89.). It should also be noted that training courses may vary depending on the results of a study

conducted by one center, which found that 21 single-port VTS upper lobectomies were sufficient for mastery of the technique, while only 12 were required for lower lobectomies (58.).
Conclusions: Minimally invasive thoracic surgery has expanded rapidly over the past decade. While multiportal VTS was the first MIS to replace open pulmonary resection via thoracotomy, many other approaches have evolved to include RVTS, single-port VTS, and suboxyfoidal approaches. The ultimate goals of these innovations are manifold and include ensuring superiority or at least equivalence to current methods; improving the efficiency of cancer diagnosis and survival outcomes; pain relief; reduction in length of stay; and decreased rates of postoperative complications.
VTS was the first approach to demonstrate superiority over thoracotomy and showed multiple benefits by increasing the intraoperative time. These benefits include reduced blood loss, reduced acute and chronic pain, reduced postoperative pain medication requirements, improved pulmonary function tests, and reduced hospitalization. Since then, RVTS has provided greater precision and maneuverability of surgical instruments with a relatively short learning curve.
Compared with thoracotomy, RVTS provides many of the same benefits as VTS and may even be superior to VTS in terms of reduced blood loss, lower conversion to thoracotomy, shorter length of stay, and better 5-year survival.
Although BMT is superior to traditional thoracotomy in reducing postoperative pain, it is still inferior to TTS in many areas. Single-portal VTS and subxiphoidal approaches allow fewer incisions to be made than conventional VTS; however, further studies are needed to confirm whether there are real benefits in terms of intraoperative and postoperative outcomes.

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